FLUID MECHANICS FOR MECHANICAL ENGINEERING (ME 208F)

Section A:
Fluid Properties & Fluid Statistics- II

Fluid Properties

Density

Density of a fluid, ρ,

Definition: mass per unit volume,

- **slightly affected by changes in *temperature* and *pressure*.**

$$\rho = \text{mass/volume} = m/\forall$$

Units: kg/m^3

Typical values:

Water = 1000 kg/m^3; Air = 1.23 kg/m^3

Fluid Properties

Specific weight

Specific weight of a fluid, γ

- Definition: weight of the fluid per unit volume
- Arising from the existence of a gravitational force
- The relationship γ and g can be found using the following:

Since $\rho = m/\forall$

therefore $\gamma = \rho g$ (1.3)

Units: N/m^3

Typical values:
Water = 9814 N/m^3; Air = 12.07 N/m^3

Fluid Properties

Specific gravity

The specific gravity (or relative density) can be defined in two ways:

Definition 1: A ratio of the density of a substance to the density of water at standard temperature (4°C) and atmospheric pressure, or

Definition 2: A ratio of the specific weight of a substance to the specific weight of water at standard temperature (4°C) and atmospheric pressure.

$$SG = \frac{\rho_S}{\rho_{W\,@\,4^\circ C}} = \frac{\gamma_S}{\gamma_{W\,@\,4^\circ C}}$$

Unit: dimensionless.

Fluid Properties

Viscosity

- Viscosity, μ, is the property of a fluid, due to cohesion and interaction between molecules, which offers resistance to shear deformation.
- Different fluids deform at different rates under the same shear stress. The ease with which a fluid pours is an indication of its viscosity. Fluid with a high viscosity such as syrup deforms more slowly than fluid with a low viscosity such as water. The viscosity is also known as dynamic viscosity.

  Units: N.s/m^2 or kg/m/s

  Typical values:
  Water = 1.14x10-3 kg/m/s; Air = 1.78x10-5 kg/m/s

Kinematic viscosity, ν

Definition: is the ratio of the viscosity to the density;

$$\nu = \mu / \rho$$

- will be found to be important in cases in which significant viscous and gravitational forces exist.

  Units: m^2/s

  Typical values:
  Water = 1.14x10-6 m2/s; Air = 1.46x10-5 m2/s;

In general,
viscosity of liquids ↓ with ↑ temperature, whereas

viscosity of gases ↑ with ↑ in temperature.

Bulk Modulus

- All fluids are compressible under the application of an external force and when the force is removed they expand back to their original volume.
- The compressibility of a fluid is expressed by its bulk modulus of elasticity, K, which describes the variation of volume with change of pressure, i.e.

$$K = \frac{\text{change in pressure}}{\text{volumetric strain}}$$

- Thus, if the pressure intensity of a volume of fluid, $\forall$, is increased by Δp and the volume is changed by $\Delta\forall$, then

$$K = -\frac{\Delta p}{\Delta\forall / \forall} \qquad K = \rho \frac{\Delta p}{\Delta\rho}$$

Typical values:Water = 2.05x109 N/m^2; Oil = 1.62x109 N/m^2

Vapor Pressure

- A liquid in a closed container is subjected to a partial vapor pressure in the space above the liquid due to the escaping molecules from the surface;
- It reaches a stage of equilibrium when this pressure reaches saturated vapor pressure.
- Since this depends upon molecular activity, which is a function of temperature, the vapor pressure of a fluid also depends on its temperature and increases with it.
- If the pressure above a liquid reaches the vapor pressure of the liquid, boiling occurs; for example if the pressure is reduced sufficiently boiling may occur at room temperature.

Engineering significance of vapor pressure

- In a closed hydraulic system, Ex. in pipelines or pumps, water vaporizes rapidly in regions where the pressure drops below the vapor pressure.
- There will be local boiling and a cloud of vapor bubbles will form.
- This phenomenon is known as ***cavitations***, and can cause serious problems, since the flow of fluid can sweep this cloud of bubbles on into an area of higher pressure where the bubbles will collapse suddenly.
- If this should occur in contact with a solid surface, very serious damage can result due to the very large force with which the liquid hits the surface.
- ***Cavitations*** can affect the performance of hydraulic machinery such as pumps, turbines and propellers, and the impact of collapsing bubbles can cause local erosion of metal surface.
- ***Cavitations*** in a closed hydraulic system can be avoided by maintaining the pressure above the vapor pressure everywhere in the system.

Surface Tension

- Liquids possess the properties of cohesion and adhesion due to molecular attraction.
- Due to the property of cohesion, liquids can resist small tensile forces at the interface between the liquid and air, known as *surface tension, σ*.
- Surface tension is defined as *force per unit length*, and its unit is *N/m*.
- The reason for the existence of this force arises from intermolecular attraction. In the body of the liquid (Fig. 1.2a), a molecule is surrounded by other molecules and intermolecular forces are symmetrical and in equilibrium.
- At the surface of the liquid (Fig. 1.2b), a molecule has this force acting only through 180°.
- This imbalance forces means that the molecules at the surface tend to be drawn together, and they act rather like a very thin membrane under tension.
- This causes a slight deformation at the surface of the liquid (the meniscus effect).

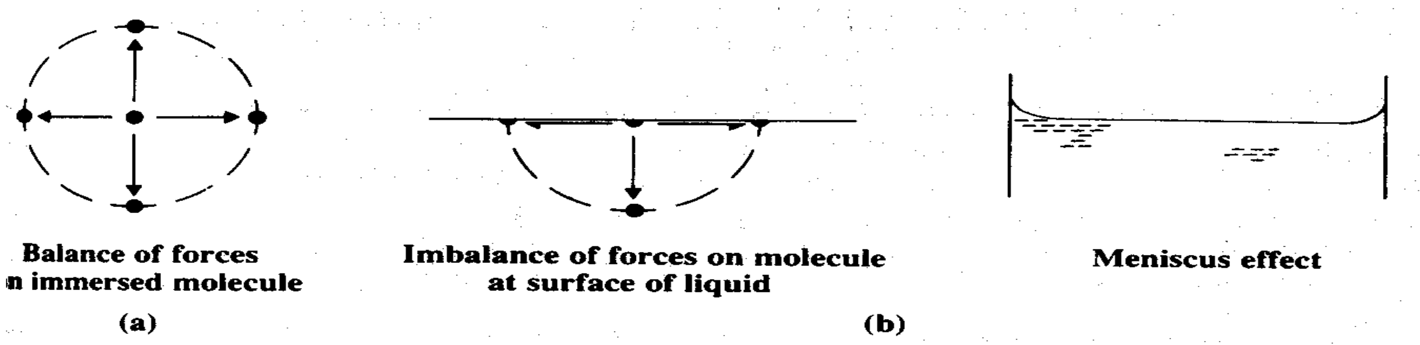


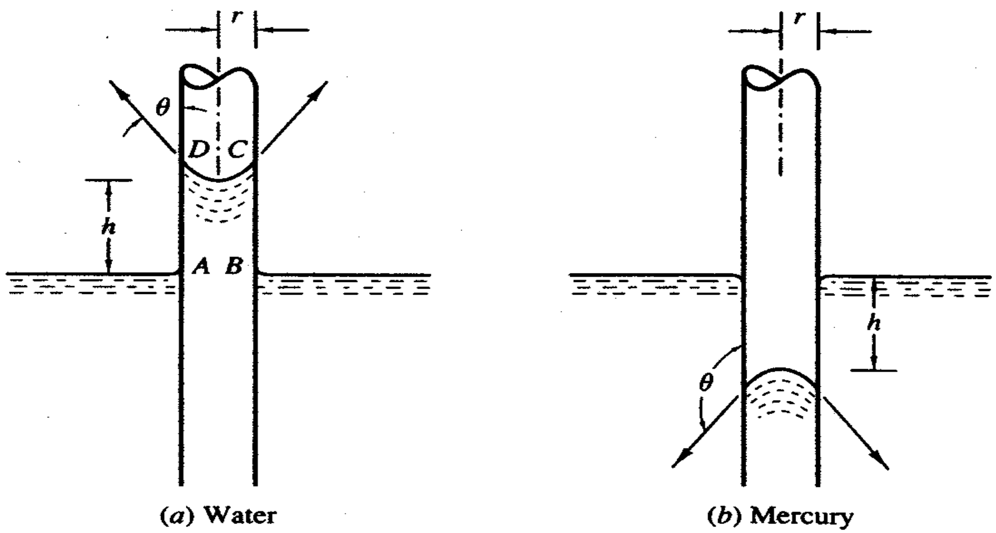
Figure 1.2: Surface Tension

- A steel needle floating on water, the spherical shape of dewdrops, and the rise or fall of liquid in capillary tubes is the results of the surface tension.
- Surface tension is usually very small compared with other forces in fluid flows (e.g. surface tension for water at 20°C is 0.0728 N/m).
- Surface tension, σ, increases the pressure within a droplet of liquid. The internal pressure, P, balancing the surface tensional force of a spherical droplet of radius r, is given by

$$P = \frac{2\sigma}{r}$$

Capillarity

- The surface tension leads to the phenomenon known as capillarity
- where a column of liquid in a tube is supported in the absence of an externally applied pressure.
- Rise or fall of a liquid in a capillary tube is caused by surface tension and depends on the relative magnitude of cohesion of the liquid and the adhesion of the liquid to the walls of the containing vessels.
- Liquid rise in tubes if they wet a surface (adhesion > cohesion), such as water, and fall in tubes that do not wet (cohesion > adhesion), such as mercury.
- Capillarity is important when using tubes smaller than 10 mm (3/8 in.).
- For tube larger than 12 mm (1/2 in.) capillarity effects are negligible.



Capillary actions

$$h = \frac{2\sigma \cos\theta}{\gamma r}$$

where h = height of capillary rise (or depression)

σ = surface tension

θ = wetting (contact) angle

γ = specific weight of liquid

r = radius of tube